CAAP Quarterly Report

Date of Report: *December 30, 2019*

Contract Number: 693JK31850012CAAP

Prepared for: *USDOT Pipeline and Hazardous Materials Safety Administration (PHMSA)*

Project Title: *Magnet-assisted Fiber Optic Sensing for Internal and External Corrosion-induced Mass losses of Metal Pipelines under Operation Conditions*

Prepared by: *Missouri University of Science and Technology (Missouri S&T)*

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For quarterly period ending: *December 30, 2019*

Business and Activity Section

(a) Generated Commitments – Dr. Genda Chen directed the entire project and coordinated various project activities.

Mr. Liang Fan and Mr. Chuanrui Guo, two Ph.D. in civil engineering at Missouri S&T, were on board since the beginning of this project. They are responsible for the fabrication and characterization test of sensors under Dr. Chen's supervision.

(b) Status Update of Past Quarter Activities – Detailed updates are provided below by task.

Task 1 Optimization of a magnet-assisted hybrid FBG/EFPI sensor enclosed in a plexiglass container for simultaneous measurement of temperature and pipe wall thickness

As shown in Fig. 1, a 3-axis magnetometer (STL Systemtechnik Ludwig GmBH; Konstanz, Germany) was used to measure the magnetic field intensity of an assemblage composed of a steel plate and a rectangular magnet placed on top of the steel plate through 16 springs. The measurement system consists of a digital sensor DM050, a three-channel coax Ethernet hub, two coax cables for data transmission, and a laptop with STL GradMag Software installed for data acquisition. The DM050 has a high resolution of 0.002 nT and its noise level is controlled under 0.06 nT/Hz. In order to measure the effect of steel plate thicknesses on the magnetic field, steel plates with a thicknesses of 3.2 mm, 8.0 mm, and 12.7 mm were tested. The test results showed that the magnitude of the magnetic field remained constant during the 10 second measurement and the intensity values decrease with the increase of the plate thickness, as illustrated in Fig. 2. Therefore, the test results prove that, as the thickness of a steel plate is gradually reduced due to corrosion, the gap between the magnet and the steel plate decreases due to the increased magnetic field intensity as a result of increasing aspect ratio of the steel plate.

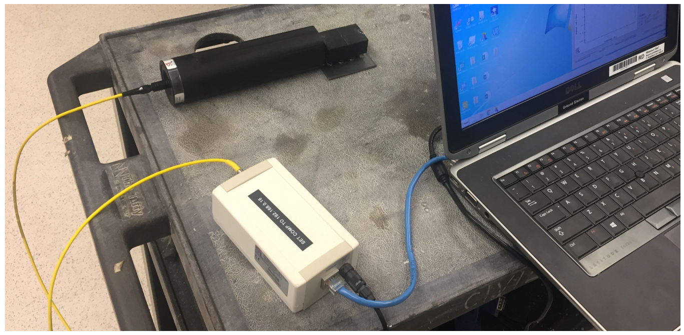

Fig. 1 STL digital flux magnetometer system.

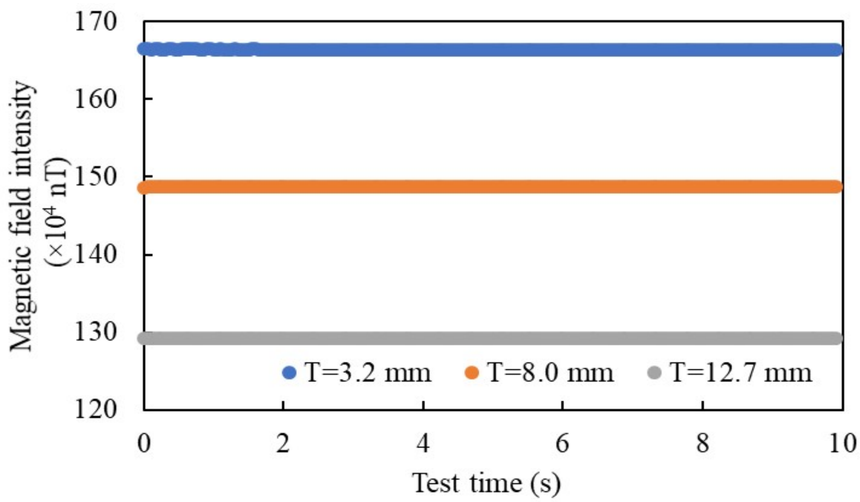

Fig. 2 Magnetic field intensity of the assemblage composed of a steel plate of different thicknesses and a rectangular magnet on top of the plate through 16 springs.

Fig. 3 shows a magnet-assisted fiber optic sensing system with a steel plate resting on top surface of a thermal heater. Two extrinsic Fabry-Perot interferometers (EFPIs) are installed between the steel plate and the rectangular magnet above the steel plate. Figs. 4 and 5 present the test results of the applied temperature vs. cavity length of the EFPI 1 and EFPI 2, respectively. Both regression lines in Figs. 4 and 5 fit into the test data very well with a correlation coefficient of over 0.98 in each case. As the temperature increases, the cavity length increases linearly. This is because the increased temperature makes the atoms inside the steel plate and magnet vibrate intensively and the vibration of the atoms leads to the disordered pattern and thus decrease of the magnetic intensity.

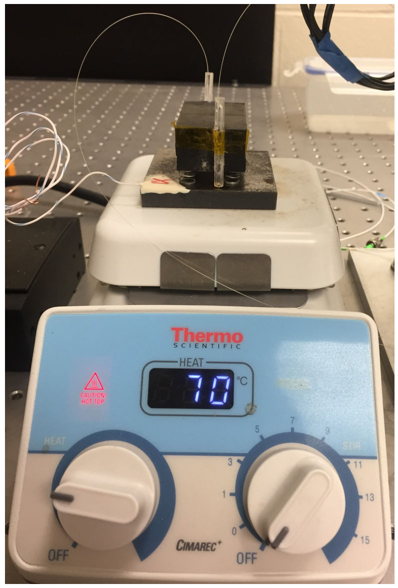

Fig. 3 The magnet-assisted EFPI sensing system on a steel plate resting on the Thermo heater.

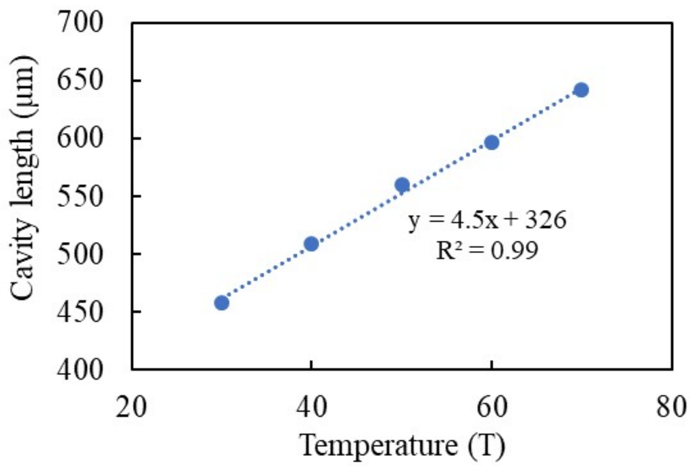

Fig. 4 Test results from EFPI 1: cavity length vs. temperature.

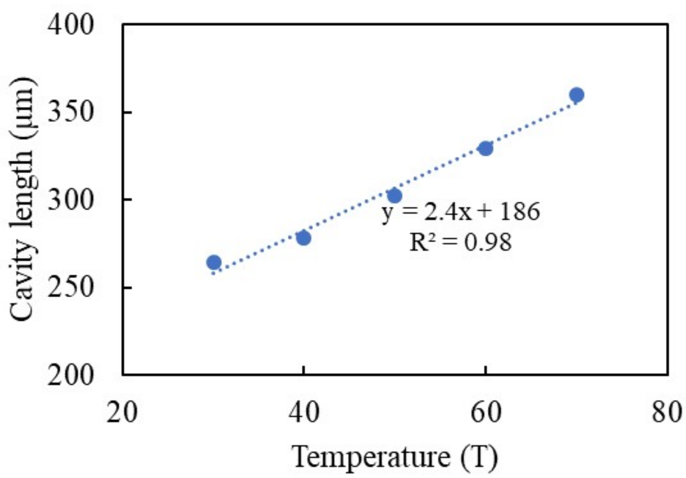

Fig. 5 Test results from EFPI 2: cavity length vs. temperature.

In order to study the effect of a cathodic potential on the performance of the EFPIs, an increasing DC voltage is gradually applied to the steel plate. The DC power applied on a pipeline depends upon the size of the pipeline and the outside coating quality. To simulate this application scenario, the applied voltage is gradually increased from 0 to 30 V in this study. The test results are presented in Fig 6. They show a stable cavity length as the applied voltage increases, indicating no effect of the applied voltage on the sensor readings.

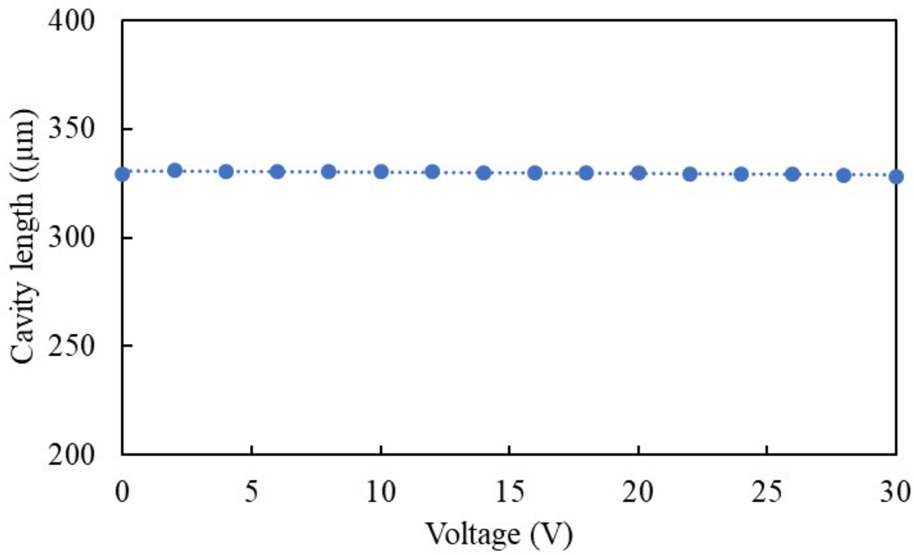

Fig. 6 Test results from a magnet-assisted EFPI: cavity length vs. applied voltage.

Task 2 Development and validation of a graphene-based LPFG sensor with Fe-C coating for improved sensitivity in mass loss measurement in varying temperature environment

To study the temperature effect on the process of corrosion monitoring, a temperature of 20, 40 or 60 ° C was applied on the Fe-C coated LPFG sensor through the temperature-controlled water bath. As shown in Fig. 7, the Fe-C coated LPFG corrosion sensor was fixed on the glass slide using marine epoxy. The fiber loop was connected to a high-speed interrogator (Micron Optics Si255) for transmission spectra acquisition. The Fe-C layer was connected to a potentiostat (model: Gamry Interface 1000E) through a copper wire using silver conductive epoxy (MG Chemicals 8331) as the working electrode during electronic impedance spectroscope (EIS) tests. Open circuit potential (OCP) was measured before the EIS. The EIS was conducted at 5 points per decade with the frequency range from 5 mHz to 100 kHz and a sinusoidal potential of 10 mV around OCP.

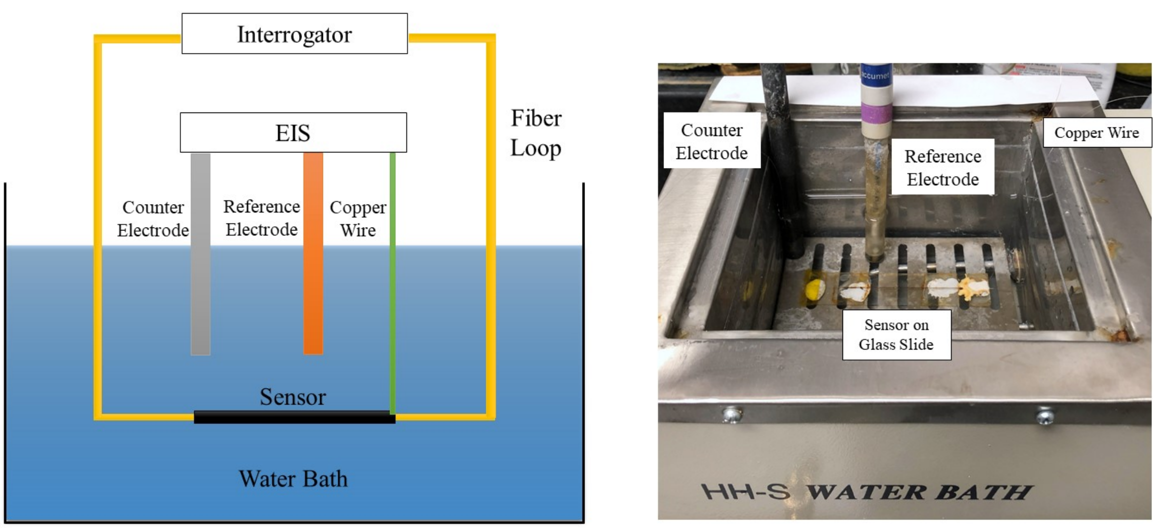

Fig. 7 Schematic view and laboratory setup of the corrosion test under various temperature levels.

The correlation between the mass loss of the Fe-C layer and the resonance wavelength shift was established using the method proposed and developed in our previous work. As shown in Fig. 8, the three stages, sensor sensitivity and transition mass loss between Stage I and II are considered to be the same for the three temperature conditions, indicating that the sensor has a robust performance for pipeline corrosion monitoring under 60 ° C.

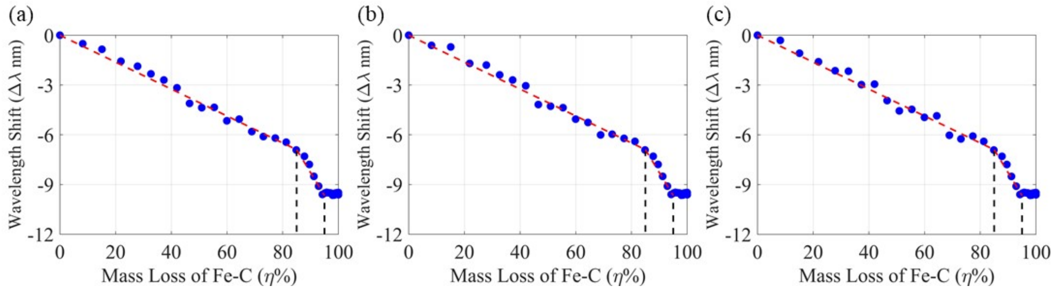

Fig. 8 Correlation between mass loss and resonance wavelength shift under three temperature levels.

Task 3 Integration and field validation of multiple FBG/EFPI and multiplexed LPFG sensors for internal and external corrosion monitoring of a pipeline with temperature compensation.

This task will not start till the 2st quarter in 2020.

***(c)* Planned Activities for the Next Quarter** - The following activities in Task 2 will be executed during the next reporting quarter.

Task 2 Development and validation of a graphene-based LPFG sensor with Fe-C coating for improved sensitivity in mass loss measurement in varying temperature environment

The evanescent field attenuation will be characterized.